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AERODYNAMIC HEATING OF THE LEE SIDE OF A BODY AT SUPERSONIC SPEEDS

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Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
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К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
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М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α	α	α	Nu	Ν	ν	
Beta	Β	β		Xi	Ξ	ξ	
Gamma	Γ	γ		Omicron	Ο	ο	
Delta	Δ	δ		Pi	Π	π	
Epsilon	Ε	ε	ε	Rho	Ρ	ρ	ρ
Zeta	Ζ	ζ		Sigma	Σ	σ	ς
Eta	Η	η		Tau	Τ	τ	
Theta	Θ	θ	ϑ	Upsilon	Τ	υ	
Iota	Ι	ι		Phi	Φ	φ	ϕ
Kappa	Κ	ϰ κ	ϰ	Chi	Χ	χ	
Lambda	Λ	λ		Psi	Ψ	ψ	
Mu	Μ	μ		Omega	Ω	ω	

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

rot	curl
lg	log

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~~AERODINAMICHESKOYE~~ Aerodynamic HEATING OF THE LEE SIDE OF a BODY AT SUPERSONIC SPEEDS.

G.I. Maykapar

It is shown that the maximum values of heat flux to the flat/plane side of the blunted semicone, directed along flow, are correlated by the parameter of "viscous interaction" $M^3/\sqrt{Re}$. Is presented the hypothesis that the reason for ~~breakaway~~ separation, appearance of "peaks" of heat flux are ~~the swallowed~~ internal shocks [illegible].

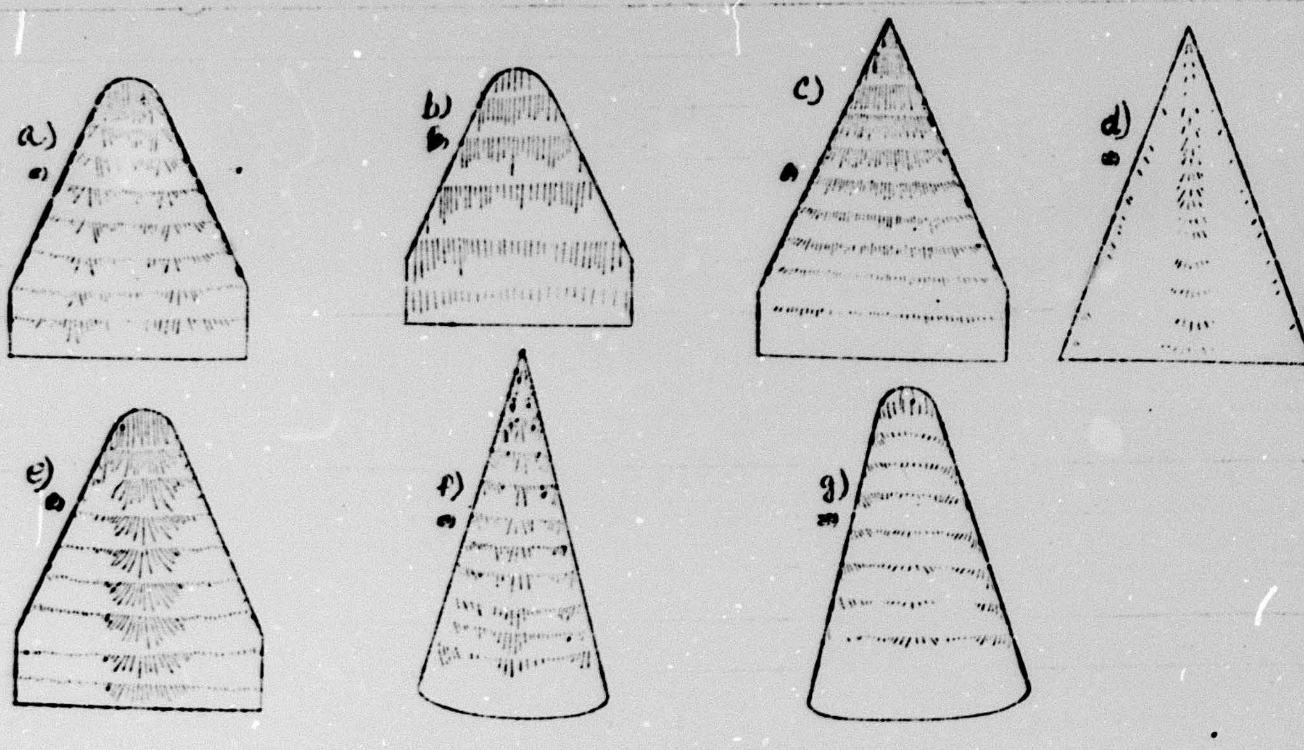
In the experimental studies of V. Ya. Borovoy, R. Z. Davletkildeyev, I. V. Ryzhkova [1], of Whitehead and Bertram [2], [3], etc. was detected the essential feature of heat transfer to the lee side of body during the detached flow of supersonic flow - the narrow ranges of the heat flux, considerably exceeding heat flux to the surrounding surface (the "peaks" of heat flux). The appearance and the ~~value~~ quantity of peaks depend on numbers M and Re, form, and the angle of attack of body. Peaks appear in the ~~ranges~~ regions of the connection of

separated flow where are great the stresses of surface friction; therefore the regions ~~ranges~~ of connection can be detected from the spectra, obtained with the aid of "blurring" ~~[illegible]~~ which by the flow of the points of color/~~paint~~. Despite the fact that is published a number ~~series~~ of the results of the investigations of heat transfer to the bodies of various forms - sharp ~~to the [illegible]~~ and blunt-nosed cones and to semicones, plates, ~~to~~ wedges, ~~to~~ elliptical cylinders, mainly in connection with the absence of the information about the general/~~total~~ structure of flows and methods of calculation, some results are difficult to explain and to confidently indicate the means for the elimination of the "peaks" of heat flux. The purpose of article is the explanation of some of the results of experiments.

Fig. 1 gives the spectra of the washed away points of color/~~paint~~ for semicones and triangular plate [1], with ~~from~~ analysis of which we will begin ~~initiate~~. A decrease in Reynolds number both because of the decrease in the pressure and decreases in the characteristic ~~significant~~ dimension, for example, a radius of the blunting of semicone, always led to a decrease in the quantity ~~value~~ of "peaks". With numbers $M_\infty \geq 5$-6, $Re_{\infty} \sim 10^4$, $Re_{\infty}/M_\infty^2 \leq 3$ (L

- the length of model) the ~~sign/criteria~~ indication of ~~breakaway~~ separation and "peaks" disappear (see Fig. 1b). There are no ~~sign/criteria~~ indications of ~~breakaway~~ separation near the point of triangular plate [4], obviously, in connection with the fact that entire shock layer (is) "viscous" and in it there is no pressure gradient, necessary for a breakaway. Since breakaway belongs to the number of phenomena of the interaction of ~~"inviscid"~~ "nonviscous" and "viscous" layers, it was possible to assume that and for it the role of the characteristic parameter will (be) play(ed by) the known parameter M^3 ~~$Re^{-1/2}$~~. By scarce experimental points this assumption was confirmed (Fig. 2), ~~according to~~ despite an inaccuracy in the determination of "peaks" and ~~to~~ the fact that the results were obtained in different wind tunnels. ~~That~~ The fact that the peaks of heat flux ~~no~~ are not on the flat/plane side of acute/sharp semicone (see Fig. 1c), and also on the convex side of ~~acute~~/sharp semicone θ_k=15° with ~~forming~~ generatrix, directed along flow [1], it is explained, obviously, by the fact that is small the "effective" angle of attack and (there is no) breakaway ~~... no~~. On the flat/plane side of ~~acute/sharp poluconus~~ sharp semicone (see Fig. 1c) are visible only ~~sign/criteria~~ indications of local separation in edges.

Fig. 1. Maximum flow lines a) the flat/plane side of the blunted semicone is directed along flow, $\theta_k=24°.3$, $\cancel{a=0}$ $\alpha=0$, $M_\infty=5$, $Re_{L,\infty}=1.1\cdot10^6$, $Re_{L,\infty}M_\infty^{-6}=70$; b) the flat/plane side of the blunted semicone, $\theta_k=24°.3$, $\cancel{a=0}$ $\alpha=0$, $M_\infty=11.3$, $Re_{L,\infty}=1.2\cdot10^6$, $Re_{L,\infty}M_\infty^{-6}=0.006$; c) the flat/plane side of ~~acute/~~sharp semicone, $\theta_k=24°.3$, $M_\infty=5$, $\cancel{a=0}$ $\alpha=0$, $Re_{L,\infty}=1.1\cdot10^6$, $Re_{L,\infty}M_\infty^{-6}=70$; d) triangular plate, $\theta_k=18°50'$, $\cancel{a=15°}$ $\alpha=15°$, $M_\infty=5$, $Re_{L,\infty}=1.3\cdot10^6$; e) the flat/plane side of the blunted semicone, $\theta_k=24°.3$, $\cancel{a=25°}$ $\alpha=25°$, $M_\infty=5$, $Re_{L,\infty}=1.1\cdot10^6$; f) the convex side of ~~acute/~~sharp semicone, $\theta_k=15°$, $\cancel{a=30°}$ $\alpha=30°$, $M_\infty=5$, $Re_{L,\infty}=10^6$; g) the convex side of the blunted semicone, $\theta_k=15°$, $\cancel{a=25°}$ $\alpha=25°$, $M_\infty=5$, $Re_{L,\infty}=10^6$.



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On circular cones the breakaway ensues at angles of attack $\alpha \approx \theta_k$, the "effective" angles of attack of semicones $\theta_k = 24^o.3$* with the flat/plane side, directed along flow, and $\theta_k = 15^o$ with ~~forming,~~ generatrix, directed along flow, less than the angles (of) "equivalent" along the space of cones ($\theta_k = 17^o.7$ and $10^o.7$ respectively). At ~~high~~ large angles of attack on the flat/plane (see Fig. 1e) and convex (see Fig. 1f) side of semicone the spectra of maximum flow lines and the peaks of heat flux are analogous to those observed in triangular plates [1] - [3] (see Fig. 1d).

It is considerably ~~with~~ more difficulty to explain the appearance of two ~~countersinks~~ peaks of heat flux on the flat/plane side of the blunt-ended semicone $\alpha=0$, to ~~α=0, by~~ which correspond two ~~ranges~~ regions of the connection of flow, which go from the points of the coupling of spherical segment with cone (see Fig. 1A), and the disappearance of these peaks ~~with~~ when the leeward convex side $\alpha=25^o$ ~~α=25°~~ (see Fig. 1g). In the latter case the peak of

*[24° 3'] ? or [24.3°] ?

lesser value, than in the case of ~~[illegible]~~ sharp semicone, appears only in the rear end of the model, but the feature in ~~of~~ heat-flow distribution[illegible], ~~[illegible]~~ connected with points[illegible] coupling of segment with cone, are also noticed [1]. There is no [illegible] ~~convincing~~ [illegible] of the reason for the appearance of two peaks of heat flux, which go from the points of the coupling of circular arc and ~~[illegible]~~ straight ~~with~~ [illegible] the rounding of the point of triangular plate [3] and of the disappearance of [illegible] the [illegible], [illegible] ~~[illegible]~~ [illegible] the formula of [illegible] [3] and of the [illegible] back [illegible] ~~[illegible]~~ of plate [4]. In order [illegible] ~~[illegible]~~ [illegible] explanation to these facts, let us examine the flow [illegible] Delta wing. We will be restricted to [illegible] [illegible], and on [illegible] which go from [illegible]. [illegible] wave number [illegible] is equal [illegible]. With the small ~~[illegible]~~ [illegible] flow pattern is [illegible] (Fig. [illegible]), [illegible] $\leqslant$ [illegible] $\leqslant$ [illegible] ~~[illegible]~~ [illegible]

$\varepsilon > \omega_1 - \varepsilon$; [illegible] if $\varepsilon > \omega_1$, then is possible only flow with the internal ~~jump of matching/seal~~ shock waves. In the case of flow with internal ~~jump~~ shock is possible both flow with the full rotation of flow before the direction of the axis of plate in ~~jump~~ shock and the flow with the lessslope angle of ~~jump~~ shock β, than in the preceding case, and by the ~~supplementary~~ additional continuous rotation of flow in ~~ramp after jump~~ region behind shock. The results of the calculations for the case of full rotation in ~~jump~~ shock are given in Fig. 4-6. The angle of internal ~~jump~~ shock ω) very is little affected with a change in angle Λ. [illegible] with angles Λ the pressure ~~after jump p_2~~ behind shock p_2 [illegible] ratio strongly rises with an increase in the angle of attack ~~a~~ α.

***********EDITOR: PLEASE CHECK FOR ALL CYRILLIC OR UNCLEAR ITEMS ON THE TABLE (FIGURE) WHICH MAY HAVE BEEN LEFT OUT***********

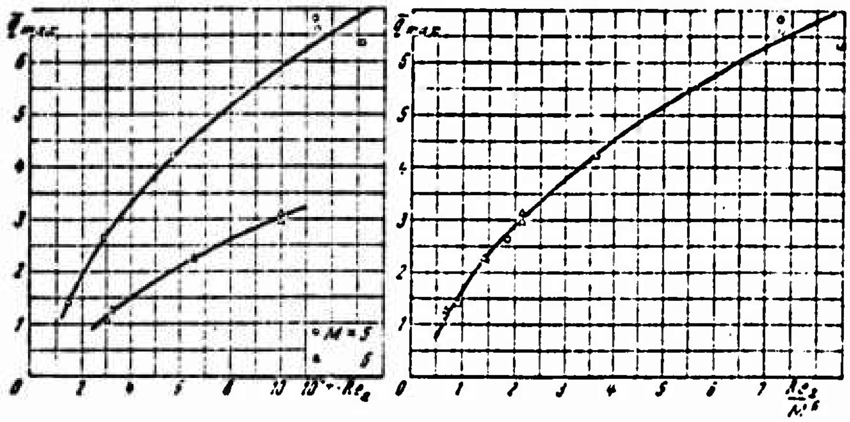

Fig. 1.

Internal theoretically
~~Swallowed~~ shocks were predicted ~~to georetichouse~~ and obtained in numerical calculations [5]. The measurements showed that their intensity first ~~grows~~/rises, and then it decreases with removal from the surface of plate.

One of the last/~~latter~~ works, in which the presence of internal shocks ~~shock~~ was established by the measurements of the total pressure, is [6]. For this investigation the characteristically low value of parameter $Re_{L,\infty} M_{\infty}^{-6} = 0.3-0.4$, [illegible] corresponding ~~range~~ regimes of "powerful" interaction. Flow separation ~~[illegible]~~ appeared during angle of attack $\alpha = 9°$ simultaneously with the ~~[illegible]~~ "suspended" ~~jump of packing/seal~~ [illegible].

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[illegible] position of [illegible] does not [illegible] plate. Boundary "[illegible]" [illegible] ~~edge~~ of plate,

in consequence of which increases the acceleration/dispersal of gas in simple wave after edge.

**************EDITOR: PLEASE CHECK FOR ALL CYRILLIC OR UNCLEAR ITEMS ON THE TABLE (FIGURE) WHICH MAY HAVE BEEN LEFT OUT************

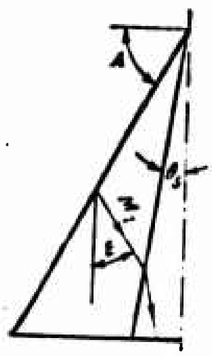


Fig. 3.

Fig. 4. Key: (1) extreme value α.

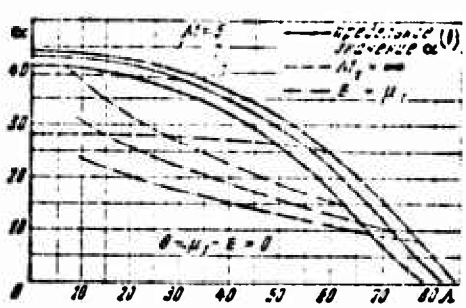
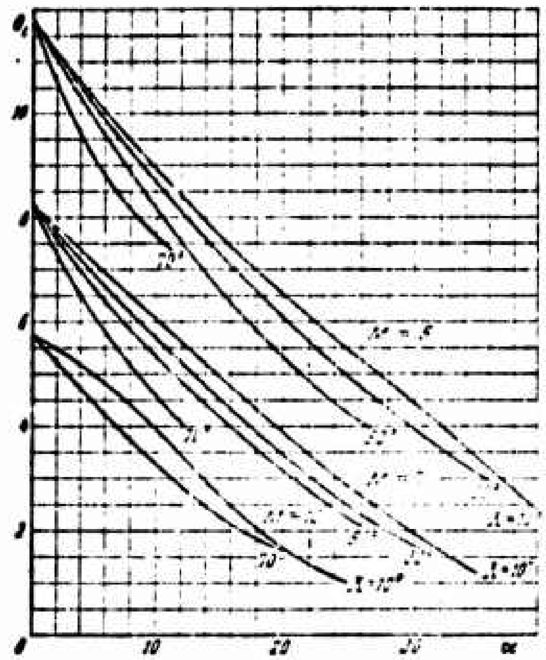


Fig. 5.



In the [illegible] of triangular plates [1] - [4] parameter $Re_{L\infty} M_\infty^{-6}$ [illegible] of order of [illegible] ~~more~~ thickness (region of "weak" interaction), the thickness of "viscous" layer - the order of the thickness of [illegible] layer ([illegible]) and [illegible] less than in investigation [4].

[illegible] with an increase in the angle of attack [illegible] layer. The [illegible] connected with [illegible] [1] - [4].

[illegible]

[illegible] of [illegible]

distance between internal ~~irregularly~~ shocks and boundary layer thickness differently change with distance from critical point of body, by the interaction of ~~[illegible]~~ shocks and boundary layer it is possible to explain a change in the ~~[illegible]~~ configuration of detached flow along the length of body and appearance instead of one peak of heat flux of the two (Fig. 7). With an increase in the angle of attack the angle between internal ~~irregularly~~ shocks decreases (see Fig. 5), in consequence of which two peaks can pass [illegible].

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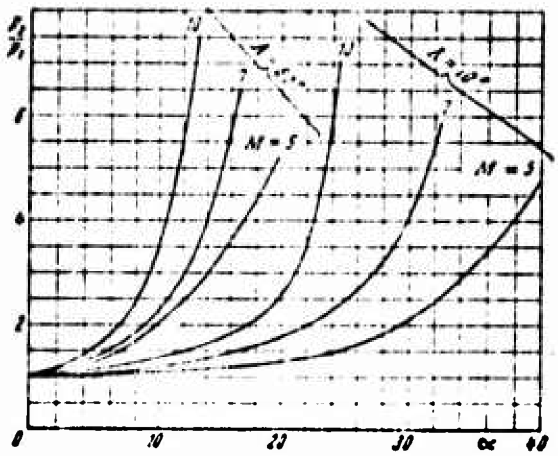

Fig. [illegible]

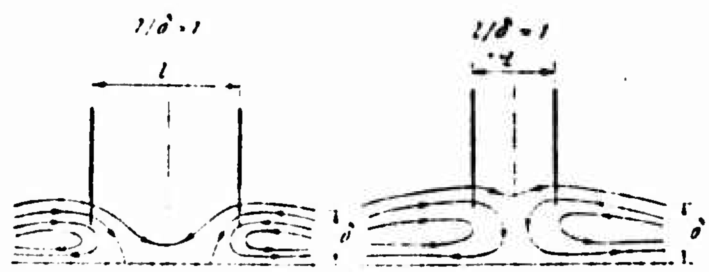

Fig. [illegible]

With an increase in the angle of attack, sweep angle Λ and ~~of~~ number M the intensity of internal ~~[illegible]~~ [illegible] the calculation, which must lead to earlier [illegible]. A decrease in angle Λ in the beginning of plate [illegible] p_2/p_1, and also, therefore, the values of the [illegible] of heat flux. At [illegible] angles of attack of plate the flow [illegible] similar to [illegible] flow, "internal" or "[illegible]" shock waves are converted into "the closing"; however, [illegible] flow the [illegible] of heat flux on [illegible] retained to [illegible] ~~[illegible]~~, although the absolute value of heat flux to the [illegible] as a result of a decrease in density [1]. Flow [illegible] of heat flux on the flat ~~plane~~ [illegible] (~~[illegible]~~, see Fig. 11), obviously, are connected with [illegible] of [illegible], [illegible] with a pressure [illegible] ~~[illegible]~~ [illegible] after fluting.

[illegible] of wedge

[illegible] to an increase in the peaks of heat flux [1].

Page 11[illegible].

The calculations show that the discontinuity ~~interruption~~ of curvature [illegible] surface of [illegible] can lead to the appearance of "suspended" shock waves [illegible] [illegible] "suspended" [illegible] in the case [illegible].

[illegible] for a laminar boundary layer, [illegible] relative value [illegible] [illegible] possible appearance of [illegible] parameters [illegible], [illegible] boundary layer and [illegible] boundary layer.

[illegible] 1

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